equivalent for 5 days after total disappearance from the park, 0.08 inch was retained for 9 days, while only 0.02 inch was retained for 13 days. The conclusions concerning the relative efficiency of forests of western yellow pine are not supported by any comparisons with other covers.—[B. C. K.]

ATMOSPHERIC INFLUENCE ON EVAPORATION AND ITS DIRECT MEASUREMENT.

By Prof. BURTON EDWARD LIVINGSTON.

[Dated: Johns Hopkins University, Laboratory of Plant Physiology, Feb. 8, 1915.]

Although evaporation has long been of interest to students of meteorology and climatology this subject seems never to have assumed prime importance in either of these branches of science. The rarity of comparative evaporation records in the United States represents a condition of affairs closely paralleled in other countries and indicates that but few workers have been vitally interested in the measurement of this climatic feature. A glance through the literature of atmometry (1) shows that evaporation has frequently attracted the attention of individuals and that its literature includes the names of many well-known students of weather and climate. Very many methods for the direct measurement of evaporation have been described from time to time during the last two centuries, but none of these has been generally adopted by weather services for any long period. This may have been due in part to numerous apparent difficulties inherent in atmometry itself, and these difficulties have aroused hopes that evaporation may become possible of calculation from data of other climatic factors. Such hopes have led some of the most able students of atmospheric physics to attempt the experimental derivation of mathematical expressions for intensity of evaporation in terms of temperature, atmospheric humidity, and wind velocity. The problem thus suggested is fascinating to the mathematical physicist, and the inadequacy of some one evaporation formula has frequently given rise to still further attempts in the same general direction, while the direct measurement of this factor has naturally been discouraged by the hope that reliable means for its calculation may soon be forthcoming.

Within the last decade, however, there has arisen a pronounced and ever increasing interest in direct atmometric measurements, an interest primarily due to the activities of plant physiologists, plant and animal ecologists, and students of agriculture and forestry. These workers have been led to study evaporation by the extreme importance of evaporation into the surrounding air in determining the activities of many organisms, especially plants and lower animals. It was early appreciated that the water relation seems to furnish a more satisfactory basis for many ecological interpretations (of the relations holding between organism and environment) than does any other single one of the various environmental relations. Plants show by their very structure and appearance their relations to the moisture conditions of their surroundings, while their temperature, light, and mechanical relations are not immediately nearly so patent and must be subjected to experimentation before even approximate determination may be possible. This point is well illustrated by the fact that ecological classifications of plant forms has generally been based upon the water relation. Simple inspection suffices to distinguish, with considerable precision, between xerophytes, mesophytes, and hydrophytes (representing various degrees of *xerophyly*) and these categories form the basis most commonly employed for the classification of vegetation forms. It is apparently obvious to the eye of the plant anatomist that a broad-leaved, deciduous forest must require more moisture than does a forest of needle-leaved conifers, and he sees just as clearly that prairie grasses, chaparral, and such forms as cacti and yuccas require less water than do ordinary forests, their water requirement decreasing in the order named. Natural vegetation areas and agricultural provinces have so far been charted mainly on this sort of basis. On the other hand, no very serious attempts have yet been made to classify vegetation forms with regard to their temperature or light relations (their different degrees of *thermophily* and of *photophily*, if such terms may be allowed).

When plant ecology began to emerge from its first descriptive and taxonomic phase attention was soon directed to the measurement of environmental conditions as these are related to plant activities. The most obvious, if not the most important, of these conditions, as far as the atmosphere is directly concerned, is the evaporation, and the instrumentation of plant habitats has made greater progress with this factor than with any other. Such progress has been made possible through a new development of atmometry.

Aside from this biological interest, it should here be noted that evaporation has long attracted the attention of irrigation and hydraulic engineers, from whose reservoirs evaporated water represents a considerable loss, even in humid regions. Also the direct loss of soil moisture by evaporation is frequently of great importance in agricultural operations, and this matter has not been neglected by students of this field.

The direct measurement of evaporation has recently attracted more attention from students of meteorology and climatology, who are coming to realize the practical futility of attempts to calculate the intensity of this factor from measurements of other atmospheric conditions.

The present paper deals with some considerations brought forward by the study of evaporation in its biological relations, but these considerations may not be without interest to climatologists, especially to those dealing with agricultural climatology.

Some general principles of atmometry.

The evaporating power[1] of the air here denotes its power to remove (or to allow the removal of) water vapor from any given exposed surface of liquid or solid water. This power is to be measured as the time rate of such removal (2).

It should be emphasized at once that the water surface from which evaporation proceeds often plays as great a rôle in the rate of water loss as do the atmospheric conditions. If different sizes, shapes, or kinds of evaporation pans, or pans containing different amounts of water, are exposed to the same complex of aerial conditions, it has been repeatedly shown that the rate of water loss per unit of surface differs for the different pans employed. If there is but slight difference between two pans, the rates of loss may appear to be the same for short-time periods, due to lack of precision in the measurements, but with pronounced differences between the pans there is no difficulty in establishing this principle.

The rate of loss in such cases is not at all directly proportional to the area of water surface exposed. *The rate*

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[1] Prof. Livingston does a service in thus emphasizing the needs for intercomparable atmometers and uniform exposures so far as the latter are attainable. The Weather Bureau feels, however, that it must protest against the use of the inaccurate and misleading expression "evaporating power of the air." As Prof. Livingston himself here defines the term, the air has no power to evaporate a liquid, only to hinder that evaporation in a greater or lesser degree.—*Editor.*

of evaporation per unit of exposed water surface, under any constant complex of aerial conditions, or with this complex varying in any specified way, is a function of the nature of the atmometer. By *nature* is here meant the size, shape, material, color, etc., of the pan as well as the height of the projecting rim, the mass of water lying behind the evaporating surface, the amount of suspended sediment, etc.

Let two dissimilar pans be exposed to the same surrounding conditions, or to the same variation of conditions for a time period, and let their respective rates of water loss be determined for that period. We may suppose that pan A loses a times as much as pan B; thus a is the coefficient of correction by which the reading of B is to be multiplied in order to give the loss from A, for the given time period and for the given set of surroundings. For the second period, let the external complex of conditions be altered or let these conditions vary in some other manner from that of the first period, and the new ratio of the loss of A to that of B will probably not now be a as before, but the coefficient of B to the basis of A will assume some new value. This is found to hold generally in experimental tests. *Thus, the ratio of the rate of evaporation from one kind of atmometer pan to that from another kind remains constant only for some single set of surrounding conditions.*

The two principles above stated may be combined as follows: *The evaporation rate from any atmometer varies with the relation between the internal complex of conditions (the nature of the instrument) and the external complex (the surrounding conditions of the atmosphere).* Emphasis is here to be placed upon the word *relation*. It is thus possible to compare the evaporating power of the air at different stations or for different time periods only by employing instruments of like internal conditions. If the internal conditions of two instruments are alike, then their rates of water loss may be compared as proportional to the two evaporating powers of the air to which they have been respectively exposed. From this it follows that evaporation can not be measured in terms of units of depth excepting for a single specified kind, size, etc., of pan. The common practice, by which different observers of evaporation employ different sizes of pans or tanks, should, of course, be discontinued, if the records are to be generally comparable.

These general principles apply as well to other forms of atmometers as they do to the form employing a free water surface. It is logically quite impossible to "reduce" readings obtained from a Piche or from a porous-cup instrument, for example, to terms of loss from any type of pan. A coefficient for such a reduction can, of course, be obtained experimentally *for any given set of external conditions, but when the conditions* alter we must expect the coefficient to alter also. Likewise, evaporation rates from different forms or sizes of porous clay cups are differently affected by the same alterations in the surroundings, and it is quite impossible to obtain a coefficient by means of which the readings of one form may be reduced to terms of readings from another, excepting with a specific set of surroundings. Nor can porous-cup losses be reduced to terms of losses from pans or paper disks.

This whole matter is clearly stated in the single sentence: *The exposure of several evaporating surfaces must be alike if their readings are to be comparable.* The evaporating surfaces possess what I would term an internal or instrumental exposure characteristic of the nature of the instrument; only when different instruments have the same characteristic may their readings be taken as measures of the external conditions, always with reference to the particular set of internal conditions [2] presented by the kind of instrument employed. Naturally, if it is desired to measure and compare the effects of the internal conditions in controlling evaporation from two dissimilar atmometers, then it is necessary to give the two instruments exactly the same external exposures. In such a case the results reflect the influence of the internal conditions, always with reference to the particular set of external ones that obtained during the period of comparison.

Summarizing the principles above set forth "the evaporating power of the air"—that is, its power to remove water vapor, or to allow its removal from a surface of liquid or solid water—can not be directly measured except with reference to some standard atmometer having specified internal conditions or characteristics. If evaporation into the air is to be measured at different places, or for different time periods at the same place, it is quite essential that the several atmometers employed shall be as nearly alike in all particulars as is possible.

Different types of atmometers.

Choice of instruments.—If the readings of one form of atmometer can not be reduced by mathematical treatment to terms of readings that might have been had from some other form of instrument (as though the latter had operated at the same time and in the same place), then by what criteria is the investigator to decide what sort of instrument to employ in a series of comparative measurements? Obviously, from the nature of evaporation and from the medley of conditions by which it is influenced, the kind of evaporation to be studied must form the basis for this decision.

Where it is desired to approximate the rate of water loss from reservoirs and other large bodies of water, the floating pan is perhaps the most suitable instrument; it exposes a free water surface in much the same manner, both internally and externally, as does the reservoir itself. Of course it is to be remembered that different parts of such a reservoir are not usually subjected to the same rate of evaporation—the windward portion of the surface, for example, is subjected to a higher rate than is the leeward portion. This makes it frequently desirable to arrange floating pans at a number of selected places over the surface of the reservoir, just as an agriculturist takes numerous soil samples from the same field, and does not rely upon a single sample taken at some particular place.

Where the study in hand involves the measurement of evaporation as it affects plant transpiration, some form of water-impregnated paper or porous clay surface is to be chosen; such surfaces may be given an internal and external exposure fairly comparable to that of transpiring plant parts. If large plants are involved (as trees in a forest), it is clear that all parts of the plant are not subjected to the same evaporation conditions, and a number of instruments must be employed, properly placed to give the required information(**3**). To study evaporation from soils, a box or pan of moist soil seems more logical as an

[2] "Characteristic" is more popular and not specific enough. A condition is an effective characteristic, one that influences the rate of the process under consideration. The rate of a process is a function of the intensities or powers of the conditions that influence it. Conditions are frequently called factors, but are not always these, in mathematical sense; they might be terms or exponents, and frequently are. Arguments is the proper mathematical term, I should say. This is not clear enough to the general reader to be here employed.

I am insisting on the retention of the more precise word "condition" and am accepting the word "characteristic" as an appositive thereto.

Phenomena occurring at any surface are conditioned or controlled in their rate by conditions, some of which are effective on one side and some on the other side of the surface.—*Author.*

instrument than does a pan of water, though water-impregnated paper and porous clay surfaces may also be adapted to this need.

In short, the surface by means of which evaporation is to be measured should possess as nearly the same form as possible and should be given the same kind of external exposure as have the evaporating surfaces whose action is to be studied.

Aside from this general principle, however, there are various special considerations connected with the use of each form of atmometer so far devised. A few of these considerations may find place here.

The free water surface.—Free surfaces of liquid water can be readily exposed only in a horizontal plane. They are therefore not suited to studies dealing with the transpiration of ordinary plants or with evaporation from other nonhorizontal surfaces. Even if this is the kind of exposure desired, it must be borne in mind that such a water surface alters from time to time, which amounts to stating that an open pan of water is not an instrument with constant internal conditions or characteristics. In the first place, wind alters the form of the surface and its relation to the water mass behind it. Also wind frequently causes spray and splashing. In most pan atmometers the amount of water present varies considerably, addition of water, to replace that lost by evaporation, occurring only spasmodically. Water is added to such an atmometer in times of rain, and raindrops frequently cause undetermined removal of water through splashing and the formation of spray. Animals, such as birds and insects, interfere with the proper operation of open tanks; they may remove water, or they may become caught on the surface or within the tank. All of these features clearly result in internal alterations in the instrument and thus make it inadequate for serious studies. Finally, even fair accuracy of reading for short periods has never been possible with free surfaces; only small pans can be carefully weighed; the instruments must be protected from wind during weighing operation, and the variations in rate of water loss due to unknown causes become very large when periods of minutes or hours are employed.

The Piche atmometer.—The Piche instrument (4) employs a horizontally placed disk of water-imbibed [3] paper, supplied with water at its center, from above. Waves and splashing, considerable removal of water by animals, and serious obstruction of the surface by the bodies of the latter, are here not encountered. The entire instrument may be readily weighed, or it may be read in volume units. Small readings are, however, difficult and not very accurate. Strong wind is apt to deform the paper disk. This instrument must always operate as a unit; it is practically impossible to place the evaporating member at a distance from the graduated reservoir, an arrangement frequently requisite in botanico-physiological and ecological studies. Since all the water evaporated must pass laterally through the paper disk, from the central point of supply to the place of final vaporization, the size of the disk must be suited to the rate of evaporation to be dealt with. In a region of low evaporation intensity the disk may be large, but must be smaller in an arid region (to prevent the edges becoming dry at times).

[3] Dictionaries say "imbibed" is obsolete, in the sense of a water-imbibed solid. Newton used it so. *It is perfectly clear (as clear as "drunk" in the expressions: The* wine is drunk by the man and the man is wine-drunk; the two words "drunk" and "imbibed" are parallel), can lead to no ambiguity, and it can not stay obsolete if we keep using it. Impregnated is not as good, because "imbibed" suggests imbibition and the attractive force of imbibition, while "impregnated" suggests pressure from without the solid as the cause of the liquid entering. There are no other words in *Roget that come as near to* what we want.

"Saturated" means an entirely different thing; the paper of a Piche atmometer may be saturated as the instrument operates; but I doubt if this is the case. It is imbibed with water, whether it is 1 or 2 or a hundred per cent saturated. Saturation implies the complete disappearance of the solid's attraction for water (imbibing force) at the limit when all the water that can be imbibed has been imbibed.—*Author.*

The Piche-Cantoni atmometer.—The Cantoni (5) modification of the Piche instrument has the reservoir below the paper disk. Practically all the essential details of operation and interpretation of readings are the same as in the Piche instrument. Exceptions are that the more or less spasmodic water movement consequent upon having the reservoir above is here avoided; also, that the evaporating surface may be located at some distance from the reservoir and at any angle permitting a more satisfactory relation to plant foliage, etc. Strong wind is apt to deform it, as also in the Piche arrangement, in somewhat the same manner as it deforms a free water surface.

It should here be pointed out that the Cantoni modification depends upon the fact that the position of the imbibed blotting-paper disk that covers the upper end of the supply tube from the reservoir below, does not permit the passage of air as a gas, so that the difference in hydrostatic pressure between the level of the paper disk and that of the water surface in the reservoir is borne as a gas pressure by the wet paper. If the joint between paper and tube is not air-tight against this amount of pressure from without, then air enters, the water column drops in the supply tube, the water connection to the disk is broken, and the disk soon becomes air-dry. This same principle is employed with the Bellani porous plate and with the Babinet porous cup.

The Bellani porous clay plate.—Bellani's (6) instrument is practically comparable to a free water surface and avoids all the difficulties of such surfaces, but appears never to have attracted serious attention during the 95 years that have passed since it was described. A horizontal porous clay disk closes the top of a vessel completely filled with water, so that the lower surface of the disk is in contact with the liquid, while the upper surface is exposed to the air. Bellani's arrangement for reading should be replaced by joining the vessel of water which adjoins the plate, by means of a tube, to a lower reservoir—which may be a burette, for example. This is the earliest form of atmometer with imbibed solid evaporating surface and with the water reservoir at a lower level than the evaporating surface. The arrangement involves the same principle as that employed in the Piche-Cantoni instrument, but here the supply tube is enlarged to form the vessel above mentioned and the porous disk does not project beyond the margin of this vessel. It should be emphasized that, whereas the Cantoni instrument (and the Piche as well) depend upon lateral movement of water through the absorbent material, the Bellani plate transmits water perpendicularly to its surfaces from the lower to the upper, and evaporation here occurs from the upper surface alone.

The Bellani surface may be exposed like free water, horizontally, or it may have any other position. It requires no projecting rim and, of course, waves, spray, and splashing can not occur. At the same time, the relation of the exposed surface to the water mass below is not markedly different (especially as regards heat conditions) from the similar relation for an open pan. The evaporating surface may be placed at some distance from the graduated reservoir and very small readings may readily be made in volume units. It may be rendered nonabsorbing, and thus freed from rain-absorption by the use of the mercury valve to be described below.

The porous clay cup atmometer.—The use of porous clay cups or bougies for atmometric measurements was first suggested by Babinet (7), whose short account was emphasized 20 years after, in an appreciative discussion by Marié-Davy (8).

Forty-six years after Babinet's publication Mitscherlich (**9**) independently devised this instrument, for agricultural experimentation. The present writer (**10**) again devised it, also independently, in the summer of 1904, for use in transpiration studies. During the last decade the subject of atmometry has developed very rapidly, especially in biological connections, and most of this development has been based upon the use of the porous clay cup.

The essential part of this atmometer is a hollow cup of unglazed porcelain, closed by a stopper at its lower end and joined, by a tube through the stopper, to a reservoir below. Cup and tube are filled with water. The porous walls of the cup become imbibed with water and the latter evaporates from the exterior and is supplied from the water-mass within, the water moving outward through the porous walls in a manner quite analogous to that exhibited by the Bellani plate above described. Atmospheric pressure acts directly upon the water surface in the reservoir below, which may be a burette or bottle, or any suitable container, and the water mass within the cup is shielded from this pressure by the imbibed porcelain, which does not allow gas to enter, except in solution. Thus the porous cup remains full of water, no matter at what rate evaporation proceeds, so long as the water level in the reservoir is above the lower opening of the supply tube, and so long as the porous material allows water movement to the surface as fast as evaporation proceeds. The amount of evaporation occurring during any time period is the amount of water removed from the entire apparatus. It is usually taken as the amount removed from the reservoir, but this, of course, neglects any consideration of alterations in the specific volume of the liquid due to temperature change. Readings are most precisely made by weighing the instrument, but such refinement is not usually requisite.

To prevent the absorption of rain water through the walls of the cup, it is only necessary to install in the supply tube a mercury valve, which allows water to pass in one direction but prevents its continued movement in the other. Figure 1 shows Livingston's atmometer as recently improved by Shive (**11**).

The valve has the following construction: The glass supply tube, *B*, reaching downward from the cup, is expanded into a small bulb, *C*, below which the tube is bent upward for a few centimeters at *B′*, and then downward again to terminate below the first bend. Mercury is placed in the U thus formed. As evaporation proceeds the mercury drops in the arm *B′* of the U and rises in the other, but immediately spreads out laterally in the bulb, thus producing only a very short column. Around this mercury in the bulb the water passes from reservoir to cup. When rain falls evaporation is so far decreased that the outer surface of the cup becomes covered with an external water film, and atmospheric pressure forces this water into the cup with a pressure equal to that exerted by a water column reaching from the water level in the reservoir to the level of the point in the cup where entrance is in progress. Then mercury is forced down from the bulb and up in the other arm of the U until a sufficient mercury column is there present to balance the water column just mentioned. After this no more water can enter the cup; that falling upon it flows from the surface as though this were impervious. When the rain ceases and evaporation increases the valve reverses. It is obvious that a small amount of water does enter the reservoir with each change from conditions of evaporation to those of absorption, but this amount is very slight. Harvey (**12**) found the error in reading thus introduced by each reversal of the valve to amount to only about 0.01 cc., this magnitude depending upon the bore of the U-tube and the height of the cup above the water level in the reservoir.

The form of porous clay cup now generally employed by workers in physiology, ecology, agriculture, and forestry, is practically the same as the one described by the present writer in 1906 (fig. 1.) These cups are cylindrical, about 13 cm. long and 2.5 cm. in diameter, closed at the upper end to produce a hemisphere and strengthened at the other by a thickened rim. The wall is from 3 to 4 mm. thick, the rim having about double this thickness. They are white, with smooth, porous and absorbent exterior surface. They are closed in use by a rubber stopper bearing the tubing connection to the reservoir. The lower portion, at the open end is glazed or otherwise rendered impervious to water, leaving the upper part, 8 cm. in length, as the actual evaporating surface. For the last few years, about a thousand of these cups have gone into use each year.

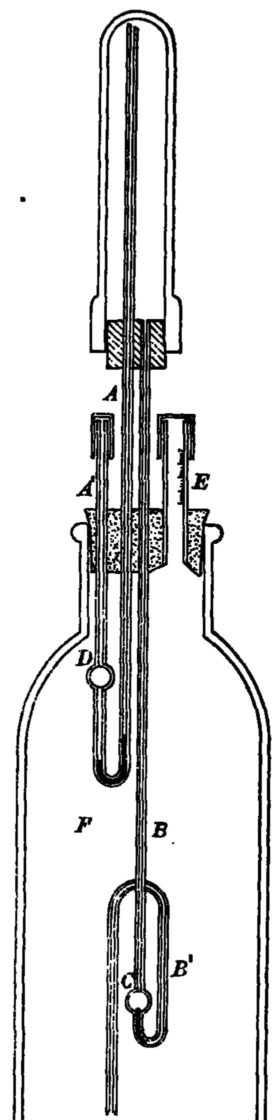

FIG. 1.—Shive's non-absorbing mounting, with cylindrical porous-cup atmometer. Above is a cylindrical porous cup with two glass tubes, *A* and *B*, entering the cup through a rubber stopper. Below is the reservoir bottle whose mouth is closed by a 4-perforate stopper. The short, graduated filling tube, *E*, is covered by a cap. The tube *ADA′* serves to fill the porous cup when suction is applied at *A′*, and the mercury valve below the bulb *D* prevents entrance of air. The second mercury valve, at *CB′*, allows water to enter the porous cup but practically prevents movement in the opposite direction.

Recently a marked improvement in the form of the cup has been achieved, first by Prof. W. L. Tower (**13**) and later by the present writer. This improvement consists in substituting a spherical surface for the cylindrical and hemispherical one of the ordinary cup. The spherical cups are 5 cm. in diameter, with a glazed, cylindrical neck below, the latter 1.5 cm. in diameter and 3 cm. long. The neck of the Tower spheres is somewhat larger and reenforced by a thickened rim. The Livingston spherical cup atmometer is shown in figure 2.

These spherical cups may become the standard [4] for atmometric studies, at least in biological connections. In this regard it is to be borne in mind, however, that readings from cylinders and from spheres can not be homologized except approximately, for they expose different forms of surface and are dissimilar in other respects. The chief practical advantage of the spherical surface lies in its greater fitness for use in the measurement of sunshine intensity, with Livingston's radio-atmometer (**14**) into a consideration of which we need not here enter.

The porous-cup atmometer possesses all the advantages over the free water surface that are possessed by the Piche, Piche-Cantoni, and Bellani instruments. Its main advantage over these instruments lies in this, that its surface projects up into the air and is exposed equally to wind action in all directions. Its surface is somewhat similar to that of plants, which is also the surface of a water-imbibed solid, and its exposure to the surrounding aerial conditions is similar to the mean exposure of the surfaces of the foliage of an entire plant. For this reason it has proved specially valuable in studies bearing upon water loss from plants. The rigidity of the cups also makes them more satisfactory than the somewhat flexible paper disks.

As with the other atmometers employing a water-imbibed, porous, solid, only distilled water should be employed in the porous cup. If impure water is used, the imbibed walls become less porous and soon become unable to transmit water to the surface as rapidly as it may be lost by evaporation. Thus the instrument itself is altered by the use of impure water. The same effect of clogging the pores may be produced by soluble salts falling on the surface in the form of dust. This difficulty can be avoided with the porous cup, and Bellani plate, by frequent and thorough washing, with distilled water and a brush. With the paper disks such washing is of course impossible and the disks must be renewed at frequent intervals.

The porous cup, the Bellani plate, and the Piche-Cantoni paper disk may all be mounted so as to permit exceedingly small readings to be made, in units of volume. With a suitable pipette as reservoir, it is easily possible to read hundredths of a cubic centimeter of loss, and this features recommends these instruments wherever low rates or short time intervals are involved.

Standardization.—It is impossible to obtain large numbers of Livingston's porous atmometer cups that are exactly alike, and the small differences met with are corrected for by the use of a coefficient of correction, obtained by standardization. A number of selected cups are preserved as standards, washed after each day's use to prevent any alteration in their porosity, etc., and one or more of these is operated upon a rotating table (**15**) along with the cups to be standardized. Thus the internal differences of the cups are measured in terms of differences in their rates of water loss under the same external conditions, and a coefficient of correction is obtained by which to multiply the reading of any cup in order to obtain the reading that would have been obtained had the place of the cup in question been occupied by a standard cup. It is well to re-standardize from time to time in order to detect any changes in the cups, but daily washing practically removes the necessity of this if the best quality of cup (known as "insoluble") is used. Nevertheless, the only way to be sure that an instrument has not altered in operation is to re-standardize it.

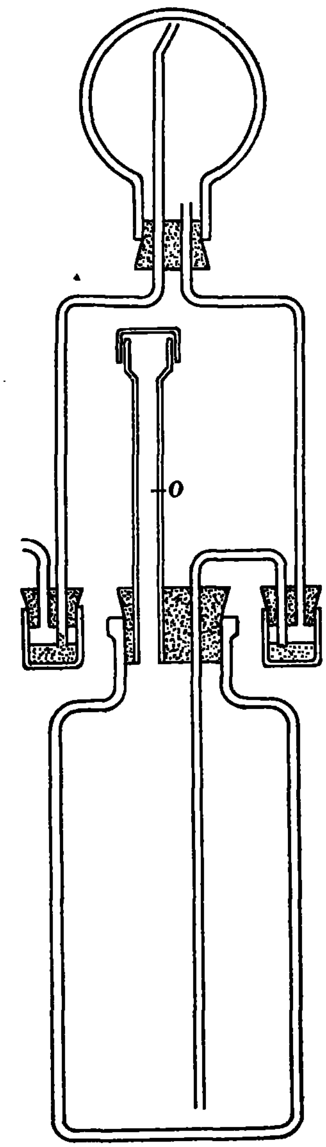

FIG. 2.—Livingston's orginal non-absorbing mounting with a spherical porous cup element. The spherical element mounted in Shive's manner is proposed as a future standard for this type of instrument.

This whole matter of standardization is obviously a drawback to the development of rational atmometry; if cups are truly different in their powers to supply water for evaporation, then—as has been emphasized—it is impossible to employ them for the comparison of different complexes of atmospheric conditions, for an alteration in these conditions can not be expected to affect the rate of loss from dissimilar cups in just the same manner. With the development of the porous cup the differences between them have been greatly decreased, so that it is now possible to procure a large number of cups all having the same coefficient. It is found in practice that it requires a very marked difference in the cups to render the coeffi-

[4] "The Plant World," Tucson, Ariz., announces that its office handles both the Livingston standard porous cup atmometer and the Livingston radio-atmometer.—C. A., jr.

cients inapplicable over the range of atmospheric conditions met with during the summer throughout the United States. Still further refinement will no doubt be attained in the future, but the instrument appears already to be amply precise for all the studies in which it has thus far been employed.

It should be remembered here that none of the atmometers employing imbibed solids are available for the study of evaporation in freezing weather. Pans of ice or of a nonfreezing solution are the only instruments thus far available for this important case of direct-measurement atmometry.

REFERENCES AND NOTES.

(1) For a résumé of this literature see—
Livingston, Grace J. An annotated bibliography of evaporation. MONTHLY WEATHER REVIEW, 1908, **36:** 181, 301, 375; and 1909, **37:** 68, 103, 157, 193, 248.
Also reprinted, repaged, Washington, 1909, 121 p. 8°.

(2) The points brought out in the present paper have been considered in a somewhat different way and more fully, in some respects, in the following publication (which also contains numerous references to the literature),—
Livingston, Burton E. Atmometry and the porous cup atmometer. Plant world, Tucson, 1915, **18:** 21–30, 51–74, 95–111, 143–149.
Also reprinted, Tucson, Ariz., 1915.

(3) See Yapp's pioneer study in this field:
Yapp, R. H. On stratification in the vegetation of a marsh and its relation to evaporation and temperature. Ann. bot., 1909, **23:** 275–319.

(4) **Piche, A.** Note sur l'atmidomètre, instrument destinée à mesurer l'évaporation. Bull. Assoc. sci. de France, 1872, **10:** 166–167.
For diagrams of this and other forms of atmometers with imbibed surfaces here mentioned, see the author's paper in the Plant world, 1915, mentioned under (2).

(5) **Cantoni, G.** Sulle condizione di forma e di esposizione piu opportune per gli evaporimetri. Rendiconti, R. ist. lomb., II, 1877, **12:** 941–946.

(6) **Bellani, A.** Descrizione di un nuovo atmidometro per servire di continuazione e fine alle reflessioni critiche intorno all' evaporazione. Gior. fis. chim., 1820, **3II:** 166–177. *Also reprinted*, Pavia, 1820.

(7) **Babinet, J.** Note sur un atmidoscope. Compt. rend., Paris, 1848, **27:** 529–530.

(8) **Marié-Davy, H.** Atmidomètre à vase poreaux de Babinet. Nouv. météorol., 1869, **2:** 253–254.

(9) **Mitscherlich, A.** Ein Verdunstungsmesser. Landw. Versuchsstat., 1904, **60:** 63–72.

(10) **Livingston, Burton E.** The relation of desert plants to soil moisture and to evaporation. Washington, 1906. 78 p. 8°. (Carnegie instit. Washington, Publ. **50.**)
A simple atmometer. Science, New York, 1908, (N. S.) **28:** 319–320.

(11) **Shive, J. W.** An improved nonabsorbing porous-cup atmometer. Plant world, 1915, **18:** 7–10.

(12) **Harvey, E. M.** The action of the rain-correcting atmometer. Plant world, 1913, **16:** 89–95.

(13) See announcement of W. L. Tower's work with the spherical atmometer cup in:
Mac Dougal, D. T. Annual report of the director of the department of botanical research. Yearbook, Carnegie institution of Washington, 1914, **12:** 71.

(14) **Livingston, B. E.** A radio-atmometer for comparing light intensities. Plant world, 1911, **14:** 96–99.
Idem. Light intensity and transpiration. Botan. gaz., 1911, **52:** 418–438.

(15) **Livingston, B. E.** A rotating table for standardizing porous cup atmometers. Plant world, 1912, **15:** 157–162.
Nichols, G. N. A simple revolving table for standardizing porous cup atmometers. Botan. gaz., 1913, **56:** 148–152.

THE INTRODUCTION OF METEOROLOGY INTO THE COURSES OF INSTRUCTION IN MATHEMATICS AND PHYSICS.

By CLEVELAND ABBE, Professor of Meteorology.

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The study of meteorology has acquired a new and vivid interest since the establishment of fairly successful official weather forecasts in this country and Europe. The civilized world now knows that the weather and the climate, the winds and storms are controlled by rigorous laws of nature; we may not understand these laws as yet, but they are in control of the universe and we are to discover them and utilize them for the benefit of mankind. We have not yet found any limit to the attainments of the human intellect, and what the mind can do in the way of thinking the hand will find some means to attain in the way of doing. We must think out our work before we can do it.

The ultimate object of all our systems of education, elementary, collegiate, and post-graduate is to train the mind to think and then train the hand to do. In old times the schools crammed the brain with the results of work already done, memorizing a multitude of facts; but now, while not neglecting the memory, we seek to develop the reasoning faculties, or the reasoning habit of thought, and then to perfect our methods of doing. Our schools pay much attention to mathematics, mechanics, chemistry, and science in general, because these have an important practical bearing on our lives. In this movement toward the professional side of education meteorology has not been neglected altogether. I have been greatly pleased to see the enthusiastic reception accorded it in every part of the Union and its growing popularity in both graded and high schools. I suppose that we owe this specifically to the general success of the Weather Bureau, but more particularly to Prof. Wm. M. Davis, who established a school of meteorology about 1878 as a division of the school of geology at Harvard University. His students and textbooks, his Elementary Meteorology and the Climatology of his successor, Prof. R. DeC. Ward, and their methods of teaching have awakened teachers and professors alike to new possibilities. Other schools and other textbooks have come into existence. The elements of the subject are now so well provided for that I do not need to say more about this; but I do feel the need of further advances.

I regard meteorology not so much as a matter of observation and generalization as matter of deductive reasoning. Our studies have approached the limit of what we are likely to discover by inductive processes. We stand where astronomy stood in the days of Laplace. We have had our Galileo and Newton, but we still need other leaders, and you will all agree with me that these must be trained in the schools. They must get their first lessons from you. Twenty or thirty years hence our future masters in meteorology will tell how their feet were turned in the right direction by the teachers of to-day.

In every school I find several boys or girls that have taken a deep interest in the weather and its relations to our lives. They are often asking questions that bear upon it. They appear to observe and understand it better than others. These are they whom I would have you secure for the possible service of the Weather Bureau. There are others that often appear dull, but are not really so; their previous education has perhaps been imperfect, some one has confused their minds with erroneous ideas from which they can not easily rid themselves. There are others who have not yet awakened to a full interest in intellectual work. In general, the school will be benefited by taking up exact and experimental work as compared with inexact, indefinite, texts or phrases. We benefit a child more than we realize when we give him exercises in exactness. Why do we make him calculate interest to the last cent? Why practice the piano or singing until he can do it properly? Why draw or paint correctly? Why speak English precisely? Is it not our conviction that what is worth doing at all is worth doing